Confronting Constellation's Radiation Challenges

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The Space Radiation Environment

Solar particle events (SPE) (generally associated with Coronal Mass Ejections from the Sun):

- medium to high energy protons
- largest doses occur during maximum solar activity
- not currently predictable
- MAIN PROBLEM: develop realistic forecasting and warning strategies

Trapped Radiation:

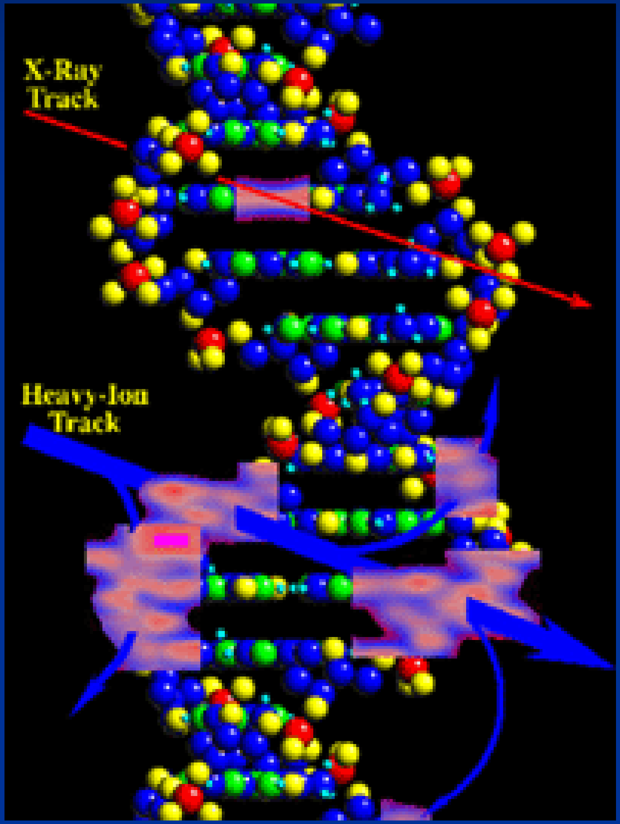
- medium energy protons and electrons
- effectively mitigated by shielding
- mainly relevant to ISS
- MAIN PROBLEM: develop accurate dynamic model

Galactic Cosmic Rays (GCR)

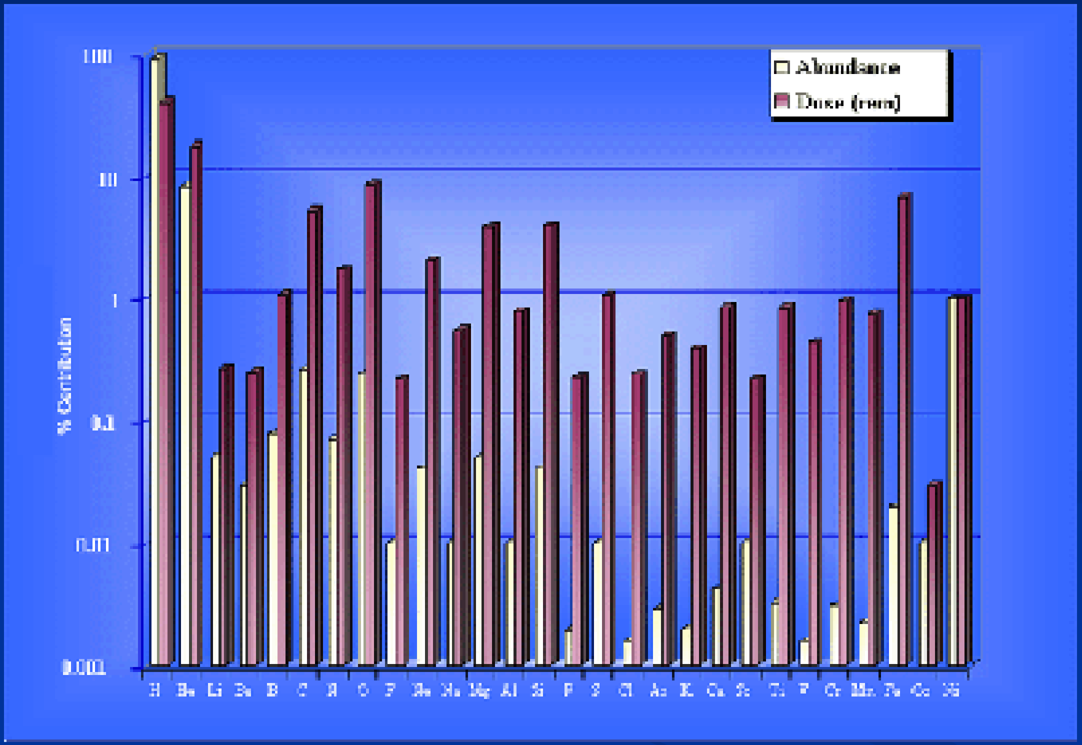
- high energy protons
- **highly charged, energetic atomic nuclei (HZE particles)**
- not effectively shielded (break up into lighter, more penetrating pieces)
- abundances and energies quite well known
- MAIN PROBLEM: biological effects poorly understood but known to be most significant space radiation hazard

Courtesy of the Space Radiation Analysis Group

The Space Radiation Problem



Double Strand Breaks



Contribution to Dose

Basis of a Radiation Protection Program

- Principles of Radiation Protection:
  - Define risks and their acceptable levels leading to exposure limits
  - Justification of activity involving radiation exposures on benefits to society
  - ALARA requirement
- Implementation
  - Establish risk projection methods and limits
  - Training of workers and specialists
  - Dosimetry
  - Maintaining records
  - ALARA documentation

ALARA

- The population involved in space activities is of limited size; thus, genetic effects would not play a role.
- The benefit of space flight exceeds substantially the risk incurred by increased exposure to radiation.
- A formal appraisal of radiation hazards would be conducted before each mission to incorporate a proper limitation of radiation risk into each mission's design.
- Actual radiation exposure of crew members would be monitored by individual and area dosimeters
- Records of all radiation exposures for every crew member would be maintained (including those from medical procedures).
- Formal protocols, including the use of calibrated active and passive measurement radiation systems,
- Flight rules covering any radiation exposure contingency have been developed and documented.

Radiation Protection Standards

- Reviewed by National Council on Radiation Protection and Measurements (NCRP Reports No. 132, No. 137, and No. 142)
- NASA Space Flight Human System Standard – Volume 1 Crew Health
- Space Permissible Exposure Limits
  - "…primary functions of preventing in-flight risks that jeopardize mission success and limiting chronic risks to acceptable levels based on legal, ethical or moral, and financial considerations."

Dose limits for short-term or career non-cancer effects

Organ	30 day limit	1 Year Limit	Career
Lens *	1000 mGy-Eq	2000 mGy-Eq	4000 mGy-Eq
Skin	1500	3000	4000
BFO	250	500	Not applicable
Heart**	250	500	1000
CNS ***	500	1000	1500
CNS*** (Z≥10) -		100 mGy	250 mGy

*Lens limits are intended to prevent early (< 5 yr) severe cataracts (e.g., from a solar particle event). An additional cataract risk exists at lower doses from cosmic rays for sub-clinical cataracts, which may progress to severe types after long latency (> 5 yr) and are not preventable by existing mitigation measures; however, they are deemed an acceptable risk to the program.

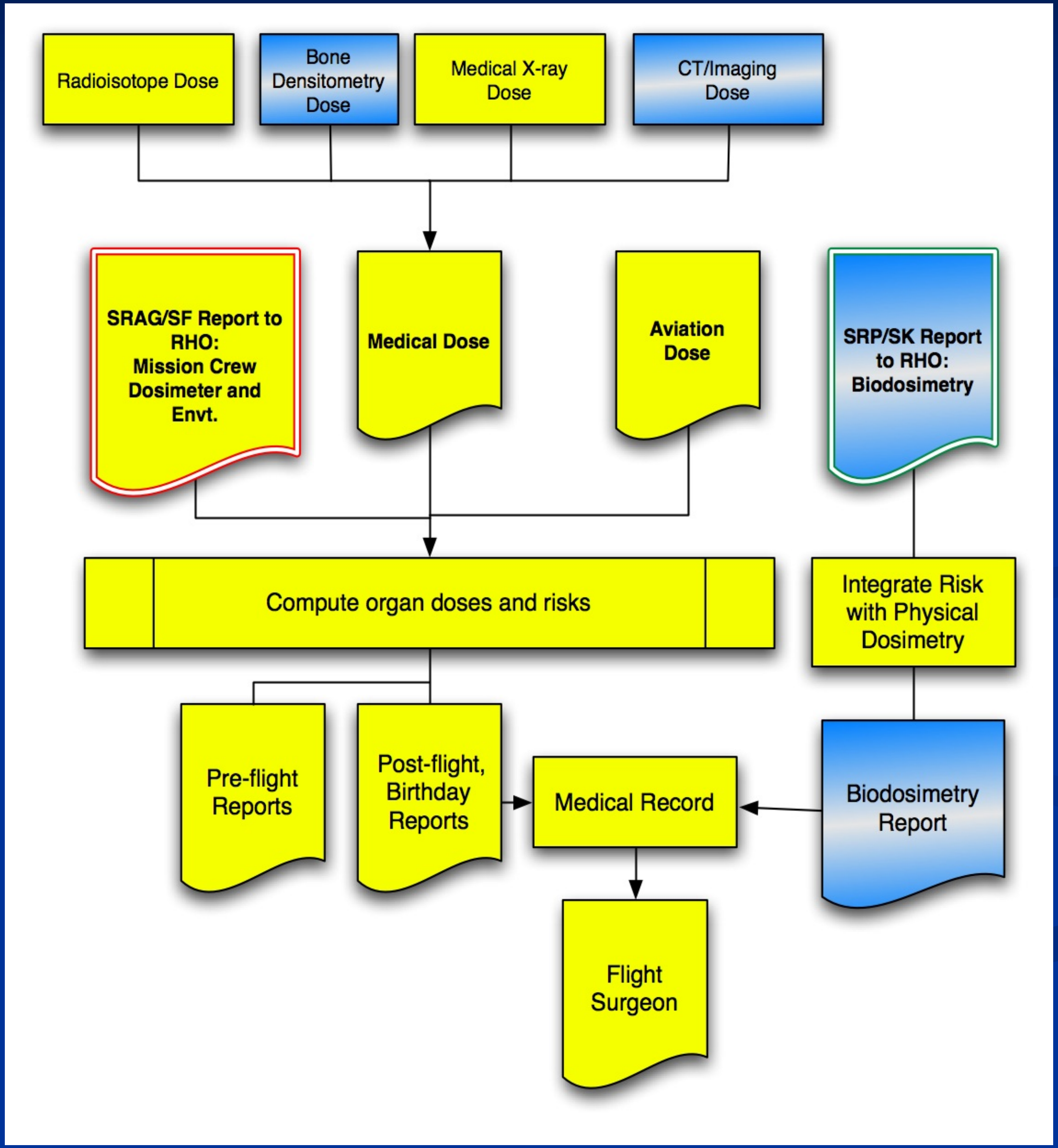
**Heart doses calculated as average over heart muscle and adjacent arteries.
***CNS limits should be calculated at the hippocampus.

Space Permissible Exposure Limits

- 3% increased risk of exposure induced death (REID) for fatal cancer
- 3% additional risk is standard for hazardous occupations and is a methodology accepted by OSHA
- In addition, standard applies a 95% confidence level to the 3% REID
- 95% confidence is conservative and is intended to account for uncertainties inherent in risk projection model
    - Epidemiology data (statistics, bias, transfer to US population)
    - Dose-rate reduction factors
    - Biological response to space radiation
    - Organ dose equivalent assessment (dosimetry, space environment, radiation transport models)
- Records maintained by Space Medicine in crew member's medical record
- Standard may continue to change over time as increased understanding allows us to improve models and narrow uncertainty

Radiation Dosimetry, Reporting, and Recordkeeping for Astronauts

Yellow: All missions
Blue: ISS Expeditions



Space Radiation Analysis Group

- Responsibilities include:
  - Radiological support during missions.
  - Pre-flight and extra-vehicular activity (EVA) crew exposure projections.
  - Evaluation of radiological safety with respect to exposure to isotopes and radiation producing equipment carried on the spacecraft.
  - Comprehensive crew exposure modeling capability.
  - Radiation instruments to characterize and quantify the radiation environment inside and outside the spacecraft.

Space Radiation Project

Research Deliverables

- Develop the Knowledge to Accurately Estimate and Reduce Risk:
- Understand radiation effects on health and performance through ground-based research
- Achieve accuracy required for cost effective risk prediction
- Develop approaches to prevent acute risks and reduce chronic risks
- Evaluate mitigation approaches (shielding or biological) for reducing risks
- Utilize data from precursor robotic missions to characterize crew exposure
- Operate and maintain the NSRL to facilitate this research
- Develop Recommendations and Requirements for:
- Risk projection models for NASA programs
- Acceptable levels of risk (acute & chronic dose limits)
- Crew constraints, mission length and operations
- Provide Capabilities:
  - Crew risk projection and analysis
  - Concept evaluation
  - Architectural and mission assessment

Missions Beyond Low Earth Orbit

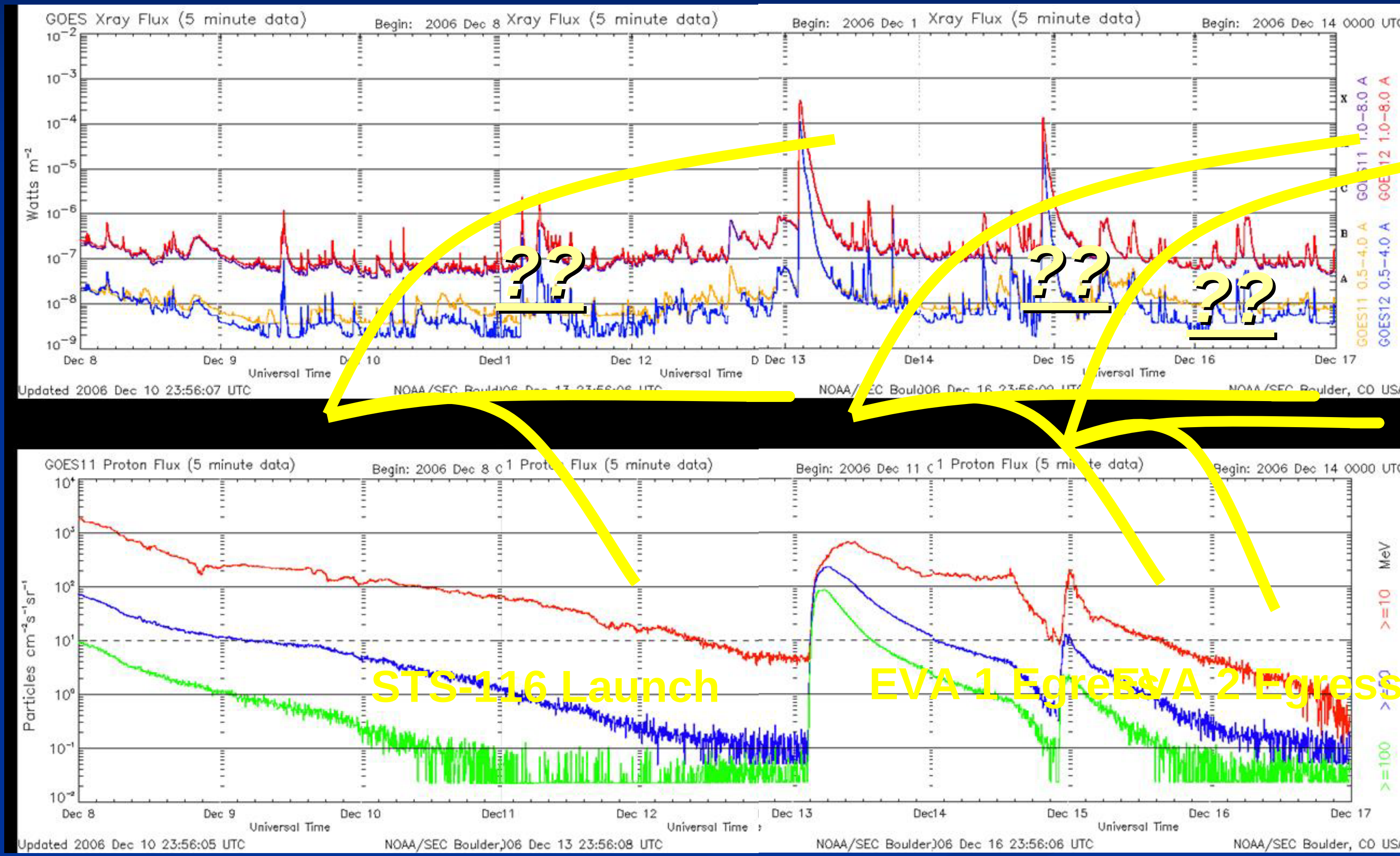
- Significant risk to crew and mission from space radiation
  - No geomagnetic protection
  - ~x10 compared to ISS
- Acceptable level of risk for exploration not determined
- NASA has chartered reviews by the NCRP
  - NCRP 153 - Information Needed to Make Radiation Protection Recommendations for Space Missions Beyond Low-Earth Orbit
  - SC 1-13: Impact of Individual Susceptibility and Previous Radiation Exposure on Radiation Risk for Astronauts
  - SC 1-15: Radiation Protection and Science Goals for Short-Term Lunar Missions
- NASA's radiation exposure limits for LEO essentially current limits for lunar operations

Information Needed

- Space Radiation Environment
  - Develop SPE forecasting and prediction capabilities
  - Develop realistic models of the largest expected SPE fluence rates
  - Continue to improve the GCR environmental models used for risk assessment
- Space Radiation Physics and Transport
  - Develop and validate space radiation transport codes
  - Improve existing nuclear interaction databases

STS-116: Example Progression

Importance of Forecasting/Prediction Ability



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Information Needed (Cont.)

- Space Dosimetry
  - Develop, certify and fly reliable rugged monitoring equipment
  - Improved neutron spectrometers
  - Experimental validation of transport and dosimetry models
  - Improved understanding of TEPC response
  - Improved organ dose assessment

Information Needed (Cont.)

- Space Radiation Biology
  - Late radiation effects (cancer/non-cancer)
  - Early radiation effects
    - Thresholds for neurovestibular, cardiac, prodromal and other CNS efffects
    - Hematological, dermal and immune issues
  - Dose rate effects
  - Countermeasure development

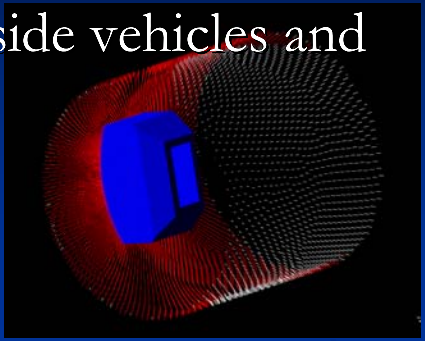
Goal: Improved Risk Assessment Model → Acceptable Level of Risk

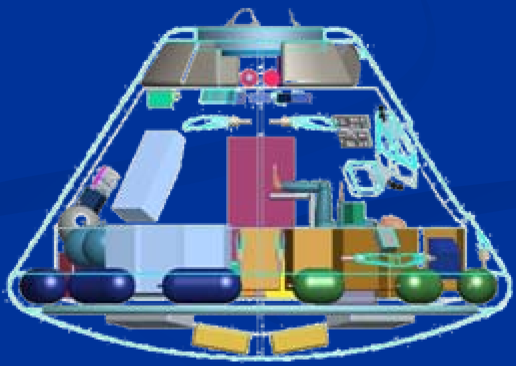
Designing Vehicles with Current Knowledge

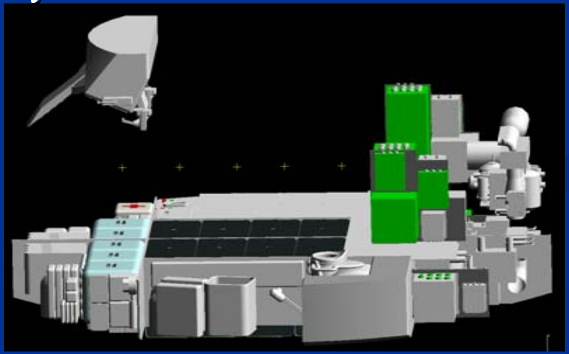
- Communicating importance of radiation protection
  - Analysis a contractor deliverable
  - Radiation System – part of Vehicle Integration Office – Spacecraft Design
- Allocation of PELs to vehicle design
- Human System Integration Standards
- Currently a “work in progress”
- Flexibility in the future will be required

Design and Response Operations

- The best opportunity for implementing ALARA inside vehicles and habitats is during the design process
- Design
  - Multi-use materials and geometry optimization
  - Radiation protection as design element
  - Provide baseline shelter
- Operations
  - Concept of Operations development ongoing
  - Risk minimization
  - Mission flexibility
  - "Worst Case"







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HSIR Radiation Design Requirement

3.2.7.1.1 Radiation Design Requirements

The system shall provide protection from radiation exposure consistent with ALARA principles to ensure that effective dose (tissue averaged) to any crew-member does not exceed the relevant value, given in Table 3.2-10, System Specific Radiation Design Requirements, for the design SPE, as specified in CxP-70023, Constellation Program Design Specification for Natural Environments (DSNE), Section 3.3.4. [HS3085]

- **Intent**: Allows the entire astronaut corps to be Cx crewmembers
  - Level II guidance at requirements development/SRR
- Exposure requirement: 3% fatal risk (35 yr-old female)
- 95th percentile environment
- No margin in the exposure requirement
  - Legalities of not excluding crewmembers
- No environment allocation guidance exists from Level II

Not a shielding requirement. As design has matured, required parasitic mass has decreased

HSIR Monitoring Requirements (3)

3.2.7.2.4 Absorbed Dose Monitoring

The vehicle shall provide an omnidirectional, portable system that can continuously measure and record the absorbed dose from charged particles with linear energy transfer 0.2 to 1000 keV/micrometer, as a function of time, at an average tissue depth of 2 mm. [HS3089]

3.2.7.2.3 Dose Equivalent Monitoring

The vehicle shall provide an omnidirectional, portable system that can continuously measure and record the dose equivalent from charged particles with linear energy transfer 0.2 to 1000 keV/micrometer, as a function of time, at an average tissue depth of 2 mm. [HS3088]

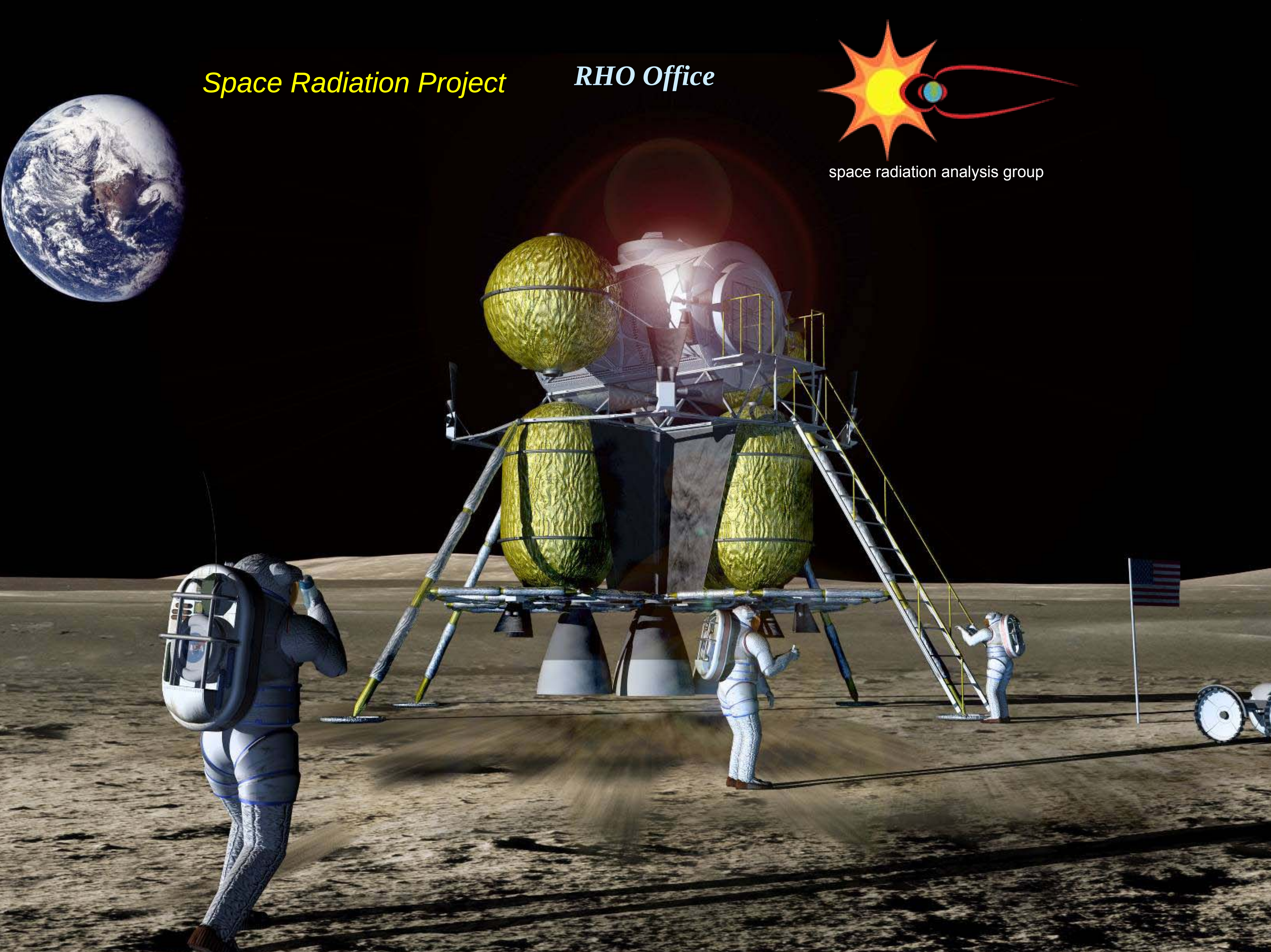
Both requirements can be met by a single instrument → currently are on Shuttle/ISS

HSIR Monitoring Requirements
(continued)

3.2.7.2.1 Charged Particle Monitoring

The vehicle shall continuously measure and record the external fluence of particles of $Z<3$, in the energy range 30 to 300 MeV/nucleon and particles of $3 \leq Z \leq 26$, in the energy range 100 to 400 MeV/nucleon and integral fluence measurement at higher energies, as a function of energy and time, from a monitoring location that ensures an unobstructed free space full-angle field of view 1.1345 Radians (65 degrees) (TBR-006-023) or greater. [HS3086]

Provides different capability than HS3088-3099.
Not redundant.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